# TUNA SURPRISE:
# Mercury in School Lunches

## Risk Management Advice for Schools and Parents

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for the
Mercury
Policy Project

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# Tuna Surprise: Mercury in School Lunches

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## Executive Summary

Canned tuna is the largest source of methylmercury in the US diet, contributing 32 percent of the total, and is a major source of mercury exposure for children. US children eat twice as much tuna as they do of any other seafood product; while the average American eats only about 100 grams of tuna (less than four ounces) a month, some tuna-loving children eat much more than that. Unusually high consumption, combined with children's small body weights, can result in mercury doses for some children that exceed federal safety guidelines, occasionally by wide margins.

Canned tuna is an inexpensive, nutritious food and is served in many school lunch programs; it is also subsidized through the USDA's Child Nutrition Program. Despite recognized public-health concerns with mercury exposure and awareness of children's developmental vulnerability, no previous research has documented mercury levels in tuna served in schools. The tuna sold to schools comes from a distinctive market sector, with its own products, brand lines and distribution systems. The best way to determine the mercury content of those products was to test them.


The Mercury Policy Project obtained 59 samples of canned tuna from this market sector in 11 states around the country, and sent them to a contract lab for mercury testing. Our samples included 35 large (66.5 oz/1.88 kg) cans and 24 large (43 oz/1.22 kg) foil pouches. The products represented six brands of "light" tuna and two brands of albacore ("white") tuna. We found that the mercury content of these products is similar to what has been reported for supermarket canned tuna by other investigators and by the US Food and Drug Administration (FDA), with several interesting specifics:

- The average mercury level in our 48 samples of light tuna was 0.118 µg/g, slightly lower than the FDA's reported average of 0.128 µg/g. Our 11 samples of albacore tuna averaged 0.560 µg/g, much higher than the FDA's reported average of 0.350 µg/g.
- Mercury levels were highly variable from sample to sample, within types of tuna, within brands and even within some packages. The average mercury content in light tuna samples ranged from 0.020 to 0.640 µg/g; in albacore, from 0.190 to 1.270 µg/g.
- 50 of our 59 samples contained tuna imported from other countries. Our nine samples of US-caught light tuna had the lowest country-of-origin average mercury level, 0.086 µg/g, and light tuna from Ecuador had by far the highest average level, 0.254 µg/g. Light tuna imported from Thailand and the Philippines averaged 0.104 and 0.108 µg/g, respectively.

- One brand of light tuna, *Northeast*, had the lowest average mercury level overall, 0.058 µg/g, and was the only product explicitly labeled as containing skipjack tuna. However, since most light tuna contains skipjack, this result was probably not species-driven, but rather a reflection of the variability of mercury levels in a wild-harvested natural product.
- Two familiar US brands, *StarKist* and *Chicken of the Sea*, accounted for 60 percent of our light tuna samples. The overall average mercury levels in the two brands were 0.131 and 0.126 µg/g, respectively, and one set of samples of each brand had much higher than average levels.

We carried out an exposure modeling exercise, summarized in **Table S-1** on page 3, to assess the risks from children's tuna consumption. Risk for a given child depends on many factors. The table illustrates the interplay of these variables:

- ***Child's weight,*** in kilograms (kg). One kg is 2.2 pounds, so a 20-kg child weighs 44 pounds.
- ***Type of tuna and mercury content.*** Mercury levels are in micrograms per gram (µg/g), also called parts per million. The values here, 0.150 and 0.500 µg/g, fall in the middle of the ranges we found in light tuna and albacore tuna, respectively, in our tests. The type of tuna eaten is not explicitly shown, but the lower value generally represents light tuna, the higher value, albacore. Mercury levels in all types of tuna vary widely, and we could have chosen higher or lower levels for each type (i.e., the table could be greatly expanded; these values are examples.) Using higher or lower mercury levels would raise or lower percents (and color codes) in the final columns.
- ***Tuna consumption,*** in grams. One ounce is 28.3 grams, so the serving sizes in the table, 57 and 170 grams, are 2 ounces (one small serving) and six ounces (three small/two medium servings). Here, too, higher or lower values could have been chosen and these are simply examples.
- ***Dose.*** The first Dose column shows the amount of mercury in micrograms (µg) in each serving, based on serving size and mercury level. The second Dose column shows the amount of mercury per kg of the child's body weight, i.e., the value in the first Dose column divided by the child's weight in the far left column. To assess risks, doses are expressed in µg/kg.
- ***Averaging time.*** The table has three sections, in which the dose is averaged over one month (top), one week (middle), and one day (bottom).
- ***Dose as percent of RfD.*** In 2000, the US government established a "Reference Dose" (RfD) for methylmercury, a definition of acceptable exposure, using evidence available at the time. More recent research, summarized later in this report, has associated adverse effects with prenatal mercury doses around or even below the RfD. In this column of the table, we express the Dose from the previous column as a percent of the RfD.
- ***Relative Risk:*** There is no "bright line" between "safe" and "unsafe" exposures, and risk is generally proportional to dose. To support more effective risk communication, we have defined six relative degrees of risk, shown by color-coding in the table. Given research showing adverse effects at or below the RfD, we defined "safest" exposure as less than 25 percent of the current RfD. Each successively higher dose level (and new color) represents a doubling of exposure.

## Table S-1. Relative Risk of Selected Tuna Consumption Scenarios

| Child's Weight | Tuna Hg, µg/g | Amount eaten, g | Hg dose, µg | Hg dose, µg/kg | Dose as % of RfD | Risk Level |
|---|---|---|---|---|---|---|
| | | Exposure Averaged over 1 Month | | | | |
| 20 kg | 0.150 | 57 | 8.5 | 0.43 | 14 | 1 |
| | | 170 | 25.5 | 1.28 | 43 | 2 |
| | 0.500 | 57 | 28.4 | 1.42 | 47 | 2 |
| | | 170 | 85.1 | 4.26 | 142 | 4 |
| 35 kg | 0.150 | 57 | 8.5 | 0.24 | 8 | 1 |
| | | 170 | 25.5 | 0.73 | 24 | 1 |
| | 0.500 | 57 | 28.4 | 0.81 | 27 | 2 |
| | | 170 | 85.1 | 2.43 | 81 | 3 |
| 50 kg | 0.150 | 57 | 8.5 | 0.17 | 6 | 1 |
| | | 170 | 25.5 | 0.51 | 17 | 1 |
| | 0.500 | 57 | 28.4 | 0.57 | 19 | 1 |
| | | 170 | 85.1 | 1.70 | 57 | 3 |
| | | Exposure Averaged over 1 Week | | | | |
| 20 kg | 0.150 | 57 | 8.5 | 0.43 | 61 | 3 |
| | | 170 | 25.5 | 1.28 | 182 | 4 |
| | 0.500 | 57 | 28.4 | 1.42 | 203 | 5 |
| | | 170 | 85.1 | 4.26 | 608 | 6 |
| 35 kg | 0.150 | 57 | 8.5 | 0.24 | 35 | 2 |
| | | 170 | 25.5 | 0.73 | 104 | 4 |
| | 0.500 | 57 | 28.4 | 0.81 | 116 | 4 |
| | | 170 | 85.1 | 2.43 | 347 | 5 |
| 50 kg | 0.150 | 57 | 8.5 | 0.17 | 24 | 1 |
| | | 170 | 25.5 | 0.51 | 73 | 3 |
| | 0.500 | 57 | 28.4 | 0.57 | 81 | 3 |
| | | 170 | 85.1 | 1.70 | 243 | 5 |
| | | Exposure Averaged over 1 Day | | | | |
| 20 kg | 0.150 | 57 | 8.5 | 0.43 | 425 | 6 |
| | | 170 | 25.5 | 1.28 | 1275 | 6 |
| | 0.500 | 57 | 28.4 | 1.42 | 1420 | 6 |
| | | 170 | 85.1 | 4.26 | 4250 | 6 |
| 35 kg | 0.150 | 57 | 8.5 | 0.24 | 243 | 5 |
| | | 170 | 25.5 | 0.73 | 729 | 6 |
| | 0.500 | 57 | 28.4 | 0.81 | 811 | 6 |
| | | 170 | 85.1 | 2.43 | 2431 | 6 |
| 50 kg | 0.150 | 57 | 8.5 | 0.17 | 170 | 4 |
| | | 170 | 25.5 | 0.51 | 510 | 6 |
| | 0.500 | 57 | 28.4 | 0.57 | 568 | 6 |
| | | 170 | 85.1 | 1.70 | 1702 | 6 |

1 **Safest:** Less than 25% of the RfD

2 **Close to Safe:** 25 to 50% of the RfD

3 **Borderline:** 50 to 100% of the RfD

4 **Some Risk:** 100 to 200% (i.e., 1 to 2 times) the RfD

5 **More Risk:** 2 to 4 times the RfD

6 **Most Risky:** More than 4 times the RfD (with no upper limit)

## Recommendations

Based on Table S-1 and on our more detailed analysis, we offer these Recommendations:

1. **Children should not eat albacore tuna.** Albacore contains roughly triple the mercury content found in light tuna. Mercury levels typical of albacore are associated with most of the orange, pink and red cells (i.e., the riskier scenarios) in table S-1. There is no particular benefit associated with albacore that can justify tripling a child's mercury exposure.

2. **Smaller children should eat light tuna no more than once a month.** Small children, with body weights less than 25 kg (55 pounds), get higher doses from a given mercury intake. Since the mercury content of all types of tuna varies widely, and some light tuna contains far more than average levels, we believe it is prudent to err on the side of caution here.

3. **Schools and parents should limit most children's light tuna consumption to twice a month.** The blue and green cells in the top part of Table S-1 show that this intake generally poses low risks (and even lower, if the tuna has less than the 0.150 µg/g of mercury we used in the table). The good news is that the majority of US children currently fall well within this consumption level. The bad news is that many children eat more tuna than this relatively safe intake, and those high-end consumers bear the brunt of elevated mercury exposure and its associated risks. (See Recommendations 4 through 9.)

4. **Schools and parents should identify children who "love tuna" and eat it often, and limit them to two tuna meals per month.** Children who eat tuna once a week or more are "tuna lovers;" their mercury exposure is far above average and is likely to pose a significant risk. It is not clear how many such children there are, because of sparse food intake survey data for young consumers, but nationally, millions of kids are "tuna lovers." The many yellow, pink and orange cells in the middle section of Table S-1 show that most children who eat tuna weekly are getting too much mercury.

5. **Children should never be allowed to eat tuna every day.** The many red cells in the bottom section of Table S-1 show how very high the mercury doses are for children who eat tuna daily. Such children are quite rare, but certainly do exist. (See the sidebars on pages 16, 17 & 18 for three cases in which children were diagnosed with methylmercury poisoning caused by their very high tuna consumption.)

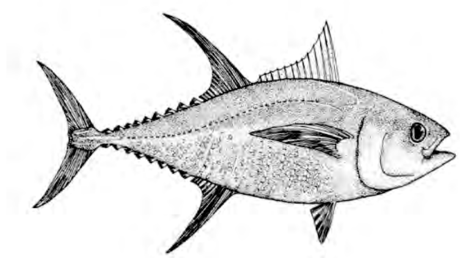
6. **Schools, parents and other caregivers should coordinate** their efforts to manage children's mercury exposure from canned tuna, since exposure is the sum of what occurs in and out of school.

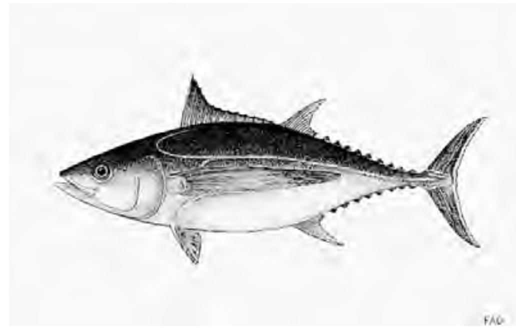
7. **Schools and parents should teach children to enjoy other seafood choices.** Salmon, shrimp and other seafood items (see Table 7, page 23) offer similar nutritional benefits but have up to 20 times less mercury than light tuna.

8. **Parents whose children eat tuna once a week or more should have the child's blood tested for mercury.** If the result is over 5 µg/L, the child's tuna consumption should be restricted and low-mercury fish should be substituted in the diet.

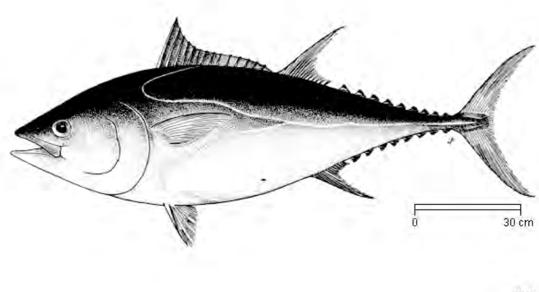
9. **The US Department of Agriculture should phase out subsidies for tuna in the school lunch program.** Canned tuna is overwhelmingly the largest source of US children's methylmercury exposure, and some children's overall mercury dose is clearly high enough to raise substantial risk concerns. There is no sound reason why taxpayer dollars should be used to subsidize any part of this risk. Over time, canned tuna can be replaced with low-mercury seafood (e.g., salmon, shrimp) and other protein sources.

10. **The US Environmental Protection Agency (EPA) and Food and Drug Administration (FDA) should expeditiously complete their ongoing effort to revise their joint advisory on seafood consumption and mercury exposure.** The updated advisory will be based on research results available since the current advisory was written in 2003, and it should not list canned light tuna as a “low mercury” choice, since it is nothing of the sort.
11. **The research and policy communities must urgently address the issue of short-term exposure “spikes.”** There is clear evidence from animal studies that brief peaks of toxic exposure during brain development have devastating effects, but it is difficult to apply that knowledge to human exposures, so this issue has largely been ignored in risk assessments. The bottom section of Table S-1 illustrates the short-term (24-hour) mercury doses, or spikes, that every child in every scenario gets on the day when they eat tuna. Most of the doses in this section exceed the RfD by wide margins, ranging up to 42-fold. While it remains uncertain how harmful such brief spikes of exposure are, the table makes clear that ordinary tuna consumption by children routinely produces high short-term spike doses. This suggests a need for additional caution in limiting children’s mercury exposure from canned tuna, and cries out for a concerted effort to reduce the uncertainties.






12. **Schools should try to avoid buying tuna from Ecuador and other Latin American countries.** Our tests and a larger earlier study (described later in this report) have shown that tuna from Latin America has consistently above-average mercury levels. When ordering from suppliers, schools should ask specifically for tuna caught by US fleets or imported from Asia.
13. **The FDA should meet with other researchers to determine why its reported mercury levels in albacore tuna are substantially lower than what other analysts have found.** Our testing is the latest of several studies (described later in this report) that have consistently found more mercury in albacore tuna than FDA’s tests have found. This disparity is puzzling and must be addressed.



# TUNA SURPRISE:
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## Background

Canned tuna is the most popular fish product, and the second most popular seafood choice overall, after shrimp, in the American diet. The average American ate 2.7 pounds (1.23 kg), or about nine five-ounce cans of tuna in 2010 (NMFS 2011). Canned tuna now makes up 17 percent of US per capita seafood consumption of 15.8 pounds (7.17 kg) per year. Canned tuna is a parental favorite, a quick and easy snack for children; for many children, it is a favorite food, and children overall eat more than twice as much tuna as any other fish (Cone 2003).

Canned tuna is also a staple of the federally-supported school lunch program, which each day serves 31.3 million of the nation's 55 million K-12 students, in 80,000 of America's roughly 99,000 public schools. An additional 20,000 private schools and day-care facilities participate in the federal program (USDA 2010). The program, which also provides breakfast, costs taxpayers $13.3 billion a year (Komisar 2011). In the 2010-2011 school year, the program purchased about 6 million pounds of tuna at a cost of about $11 million, down from 10 million pounds in 2008.

Canned tuna is tasty, easy to prepare, relatively low-cost, widely available, and nutritious. It is rich in high-quality protein, low in fat, and almost entirely free of saturated fat. Different kinds of tuna provide differing amounts of omega-3 polyunsaturated fatty acids, which promote nervous system development and cardiovascular health. Unfortunately, though, canned tuna is also far and away the largest source of exposure to methylmercury in the US diet. According to a recent analysis, it accounts for almost 32 percent of the total amount of mercury in the US seafood supply (Groth 2010).

Methylmercury is formed in the environment by microbes that convert inorganic mercury from natural and pollution sources into the organic form, which accumulates in the food chain. Essentially all human exposure to methylmercury comes from fish and seafood consumption. Most fish contain at least traces of it, but the highest levels occur in long-lived, predatory species, a category that includes tuna. Canned tuna's popularity, combined with its relatively high methylmercury content, makes it a more important source of exposure than other fish, like shark and swordfish, that contain more methylmercury but are eaten much less often.

There are two main types of canned tuna: The so-called light or "chunk light" variety, which is generally skipjack but may also contain yellowfin, bigeye or tongol (Food News 2009), makes up about three-fourths of the market; "white" tuna, which is albacore, makes up the other quarter. The US Food and Drug Administration has tested hundreds of samples of canned tuna for mercury over many years (FDA 2012); FDA data show that albacore tuna contains about three times as much mercury as light tuna does, ranking it among the highest-mercury species commonly consumed in the United States.

The methylmercury content of canned tuna raises public health concerns, especially with respect to consumption by women of childbearing age and children. The current federal advisory, issued jointly by the FDA and the US Environmental Protection Agency (EPA) in 2004 (FDA 2004), recommends that women and young children limit their intake of canned albacore tuna but recommends light tuna as a lower-mercury choice that women can consume at up to 12 ounces (340 g) a week. (But canned light tuna has an above-average mercury level compared to the overall US seafood supply.)

A growing body of evidence, most of it published since the 2004 advisory was issued, strongly suggests that prenatal mercury doses well within the range of ordinary exposure, associated with as little as two fish meals per week, can adversely affect children's developing brains. At the same time, strong evidence has emerged that fish consumption during pregnancy provides omega-3 fatty acids that are essential for brain development. The current consensus is therefore that women of childbearing age and children should eat fish, but should choose low-mercury varieties (e.g., Oken et al. 2012).


While research has focused on prenatal methylmercury exposure, children's nervous, immune and other systems continue to grow and develop throughout childhood and into early adulthood. Methylmercury exposure from children's fish consumption is thus an important public health concern, but has not been extensively studied. On one hand, millions of children have eaten tuna regularly for decades, with no apparent harm. On the other hand, little research has specifically looked for possible neurodevelopmental effects of tuna consumption by children. Recent evidence that even everyday prenatal exposures can have subtle but significant adverse effects indicates that closer scrutiny of this topic is warranted.

Risk from methylmercury exposure is proportional to dose. The risk tuna consumption poses for a given child depends on several factors, including the amount and type of tuna the child consumes, mercury levels in the tuna, the child's body weight and developmental stage, the time over which the tuna is consumed, and numerous personal traits that affect susceptibility to toxic effects. It may be perfectly safe for most children to eat a tuna sandwich now and then, but children who love tuna and eat it often can get methylmercury doses that at best can no longer comfortably be regarded as safe, and, in more serious cases, fall in a range that clearly seems potentially harmful.

To keep this risk in perspective, only a small fraction of children probably eat enough tuna to be at risk (e.g., recent studies, discussed later in this report, found adverse effects in children with the highest 10 percent of prenatal mercury exposures). However, to manage that risk effectively, parents, school dietitians and others who decide what children are fed need more and better information about the risks involved, and useful guidelines to identify and prevent situations that can put children at risk.

The focus for this report is canned tuna served in school lunches. We carried out a test project to determine mercury levels in canned tuna purchased by schools. The mercury content of canned tuna in general is well known and not in dispute. However, no previous published data, as far as we can tell, sampled the canned tuna sold to schools and other institutions. While there is no reason to suspect that tuna in schools would differ in mercury content from tuna sold in supermarkets, the tuna sold to institutional customers is a distinct market sector, with its own products, brand lines and distribution chains, and the best way to determine its mercury content was to test it.

After obtaining samples of tuna from schools and testing them for mercury content, we carried out a risk assessment to guide parents and school officials seeking to manage children's mercury exposure from this popular dietary staple.


## Materials and Methods

We recruited volunteers from across the country and asked them to invite local school districts to participate in our research by providing samples. We had difficulty getting school districts to cooperate, because of government regulations (foods cannot legally be diverted from the subsidized school lunch program) and fear of legal liability (several school officials told us they worried about being sued if they *knowingly* fed mercury-containing fish to their students; our offer to share our test results with them was therefore counterproductive.)

Eventually, we were able to sample this market sector. Some school officials did give us samples, and others told us where they bought their tuna so we could buy samples from the same distributors. We learned that other institutions, such as colleges and hospitals, buy the same tuna products from the same distributors, and we obtained some samples from colleges and universities, which were generally more inclined to cooperate with our project than public school districts were. We ultimately collected samples from 12 sources in 11 states. Five sources were public school districts, five were colleges or universities, and in two cases we bought samples directly from distributors schools referred us to.

We collected 59 samples. The majority (35) were large (66.5 oz, 1.88 kg) cans; the rest (24) were large (43 oz, 1.22 kg) laminated foil pouches. Each sample was assigned a random three-digit number, and labels were removed from the cans (this was not possible with the laminated pouches), to blind the analytical laboratory to the identity of the sample. Samples were shipped to Micro Analytical Systems, Inc. (MASI), in Emeryville, CA. MASI owns a contract laboratory and operates the Safe Harbor™ test program, assaying the mercury content of seafood for commercial customers such as supermarket chains that wish to certify that the fish they sell have acceptably low mercury levels.

The laboratory opened each package and took three small "bites" (about 5 grams each) of tuna from different parts of the package. They then divided each bite in half and analyzed it in duplicate. This procedure yielded six data points per package and an internal check for each paired subsample.

The analytical process MASI uses is proprietary. While it is based on a well accepted and widely used analytical method for mercury in foods, the company has incorporated several advances in terms of the amount of material required, automation, and speed of the process. The method as a whole is the core of MASI's business, and their most valuable intellectual property, and they have kept the details private. However, their method has been validated in round-robin tests with other laboratories, and we have complete confidence in the accuracy of their results.


Testing for this project followed standard good laboratory practices and quality assurance methods: The analytical system was calibrated frequently and certified reference materials were included in each batch of tested samples, with consistent accuracies within ±2 percent.

Our samples were tested for ***total mercury***. Although methylmercury is the specific compound of greatest concern, it is well established that about 90 percent of the mercury in tuna is methylmercury (Bloom 1992, Lasorsa and Allen-Gil 1995). Testing for methylmercury is more time-consuming and costly but yields results very close to tests for total mercury; most investigators therefore consider results of the two tests essentially equivalent, and as we did, test for total mercury.

## Results

Products Obtained: Our 59 samples included seven different brands of tuna. The pouches consisted of two Brands, *Chicken of the Sea* (obtained from two states) and *StarKist* (obtained from four states). Our cans came from six states, with a different brand in each case. Product details are shown in **Table 1 (page 5)**.

Types of Tuna: Ten of our 12 sets of samples were "light" tuna; two sets were albacore tuna.

Countries of Origin: Two sets of *StarKist* samples carried no country-of-origin information, indicating that the tuna were caught by US fishermen. Ten sets contained imported tuna, mostly from Southeast Asia—Thailand, the Philippines and Indonesia. One set of samples had tuna from Ecuador.

Mercury Levels: Our complete test results are presented in the **Appendix** and are summarized in **Table 2 (page 6).**

## Table 1. Products Tested

| Where Obtained | Product Name | Package & Size | Country of Origin | Production Code(s) | Distributor |
|---|---|---|---|---|---|
| VT | Ambrosia Quality Foods White Chunk Albacore Tuna in Water | 1.88 kg cans | Indonesia | NA | Schreiber Foods International Ramsey, NJ 07446 1-800-631-7070 |
| GA | Chicken of the Sea Solid White Albacore Tuna in Water | 1.88 kg cans | Thailand | 55ABC 2ZSWX | Chicken of the Sea Intl. San Diego, CA 92121 |
| CA | Chicken of the Sea Premium Wild-Caught Light Tuna in water | 1.22 kg foil pouches | Thailand | 5W1B1 | Chicken of the Sea Intl. San Diego, CA 92121 |
| WI | Chicken of the Sea Premium Wild-Caught Light Tuna in water | 1.22 kg foil pouches | Thailand | 59N11 | Chicken of the Sea Intl. San Diego, CA 92121 |
| CA | Deep Blue Chunk Light Tuna in Water | 1.88 kg cans | Philippines | 1CSCB 110608 | Camerican International Paramus, NJ 07652 |
| IL | Empress Chunk Light Tuna in Water | 1.88 kg cans | Philippines | NA | Mitsui Foods, Inc. Norwood, NJ 07648 |
| NY | Northeast Brand Chunk Light Skipjack Tuna in water | 1.88 kg cans | Thailand | T11C4L K LK607 2 B2021, -8, -9 | Northeast Marketing Co. Lakeville, MA 02347 |
| FL | StarKist Chunk Light Tuna in water | 1.88 kg cans | Thailand | 1225J4 9B KJW K6 | StarKist Co. Pittsburgh, PA 15212 1-800-252-1587 |
| MA | StarKist Chunk Light Tuna in water | 1.22 kg foil pouches | Not stated (USA) | 0 308 SM 2A CJWF6 | StarKist Co. Pittsburgh, PA 15212 1-800-252-1587 |
| NJ | StarKist Chunk Light Tuna in water | 1.22 kg foil pouches | Not stated (USA) | 0277 SM 1J 0300 SM 1G CJWF6 | StarKist Co. Pittsburgh, PA 15212 1-800-252-1587 |
| NC | StarKist Chunk Light Tuna in water | 1.22 kg foil pouches | Ecuador | 1105GE DG CBWF3 | StarKist Co. Pittsburgh, PA 15212 1-800-252-1587 |
| ME | World Horizons Chunk Light Tuna in Water | 1.88 kg cans | Philippines Thailand | SCV11P23F11 U68N2CBNH 1 PDMB | Unipro Food Service Inc. Atlanta, GA 30339 |

The most striking feature of the data is the ***variability*** of mercury levels in the canned tuna we tested. Tuna, like any other wild-harvested food, is naturally quite variable. Commercial canned tuna consists of several different species of fish, caught in widely dispersed parts of the world's oceans. The individual fish caught can vary widely in age and size. Since each of these factors affects mercury content, it is not unexpected that mercury levels vary widely.

Variation was seen even within individual packages. While the three "bites" tested from most cans or pouches typically differed by only two-fold or less, results for some packages differed by 5- to 10-fold, and in one case, 21-fold. Across all samples of the same product (from 4 to 19 packages per product), the mercury levels in our two brands of albacore tuna varied by 3-fold and 6-fold, while among our six brands of light tuna, mercury levels within a product varied by from 6-fold to 32-fold.

**Table 2. Summary of Mercury Test Results by Product and State**

| Product Tested | Where Obtained | No. of Samples | Average Hg, µg/g | Range, µg/g |
|---|---|---|---|---|
| Deep Blue Chunk Light Tuna in Water | CA | 5 | 0.111 | 0.03 - 0.19 |
| Chicken of the Sea Premium Wild Caught Light Tuna in Water | CA | 5 | 0.068 | 0.02 - 0.26 |
| StarKist Chunk Light Tuna in Water | FL | 5 | 0.088 | 0.04 - 0.13 |
| Chicken of the Sea Solid White Albacore Tuna in Water | GA | 5 | 0.771 | 0.21 - 1.27 |
| Empress Chunk Light Tuna in Water | IL | 5 | 0.114 | 0.04 - 0.26 |
| World Horizons Chunk Light Tuna in Water | ME | 4 | 0.126 | 0.03 - 0.31 |
| StarKist Chunk Light Tuna in Water | MA | 5 | 0.093 | 0.03 - 0.20 |
| StarKist Chunk Light Tuna in Water | NJ | 4 | 0.079 | 0.02 - 0.13 |
| Northeast Chunk Light Skipjack Tuna in Water | NY | 5 | 0.058 | 0.01 - 0.21 |
| StarKist Chunk Light Tuna in Water | NC | 5 | 0.254 | 0.05 - 0.64 |
| Ambrosia White Chunk Albacore Tuna in Water | VT | 6 | 0.384 | 0.19 - 0.62 |
| Chicken of the Sea Premium Wild Caught Light Tuna in Water | WI | 5 | 0.184 | 0.04 - 0.31 |

This variability is not surprising; it reflects the expected statistical distribution of levels in individual samples (e.g., see Karimi et al, 2012). Average levels in tuna of different types, brands and origins are equally important, because the risk of adverse health effects depends at least in part on long term average exposure. However, since risk may also be influenced by peak exposures, i.e., short-term elevated "spike" doses, sample-to-sample and within-brand variability also needs to be considered in risk assessments.

## Data Analysis

The differences in average mercury levels shown in the fourth column of **Table 2** were analyzed for their association with three variables: type of tuna, country of origin, and brand. The state where we obtained a given set of samples is identified in the tables for information purposes, but our sampling was not designed to shed light on differences in mercury levels from place to place around the country (and over the long term, none seem likely). Any differences in mercury levels in tuna from different states can be attributed to specific characteristics of the tuna—primarily, type of tuna and country of origin—not to where we got the samples.

**Table 3. Mercury In Tuna, By Type of Tuna**

| Tuna Type | No. of Samples | No. of Analyses | Average Hg, µg/g | Range, µg/g |
|---|---|---|---|---|
| "Chunk Light" | 43 | 258 | 0.125 | 0.02 - 0.64 |
| "Light Skipjack" | 5 | 30 | 0.058 | 0.01 - 0.21 |
| Albacore | 11 | 66 | 0.560 | 0.19 - 1.27 |

__Type of Tuna__: **Table 3** shows mercury levels in the different types of tuna we tested. The difference between mercury levels in canned light and canned albacore tuna in our test results was highly statistically significant ($p = 0.0002$).

The FDA has been testing canned tuna for mercury since the 1970s. In the past 20 years, FDA has tested 551 samples of canned light tuna and 451 samples of canned albacore tuna, finding an average of 0.128 µg/g (range from not detectable to 0.889 µg/g) in light tuna, and an average of 0.350 µg/g (range from not detectable to 0.853 µg/g) in albacore (FDA 2012). As we did, FDA measures total mercury in its tuna samples. The difference in mercury content between albacore and light tuna has also been repeatedly confirmed by independent testing (e.g., Consumer Reports, 2006, 2011; Burger and Gochfeld 2004) and is a well-established fact.

As we did, most other investigators have also found higher mercury levels in albacore than reflected in the FDA database. Burger and Gochfeld (2004) found an average of 0.407 µg/g, with a maximum of 0.997 µg/g, in 123 cans of white tuna from New Jersey. Gerstenberger et al. (2010) tested 130 cans of "chunk white" tuna from Las Vegas, Nevada and found an overall average mercury level of 0.619 µg/g. Three brands they sampled had average levels of 0.502, 0.566 and 0.777 µg/g and maximum levels of 0.869, 1.144 and 1.666 µg/g, respectively. The same authors tested 49 cans of "solid white" tuna from one brand and found an average of 0.576 µg/g and a maximum of 0.988 µg/g in that product. Malsch and Muffett (2006) tested 20 cans of albacore from US and Asian fisheries and found an average mercury level of 0.401 µg/g and a maximum of 0.730 µg/g. In an earlier test report, the Mercury Policy Project analyzed 48 cans of albacore tuna and found an average mercury level of 0.506 µg/g and a maximum of 1.10 µg/g (Bender 2003).

The two brands of albacore we tested had very different mercury levels. The *Ambrosia* brand, obtained in Vermont, had an average of 0.384 µg/g, with individual bites that ranged from 0.19 to 0.62 µg/g. In contrast, our *Chicken of the Sea* albacore tuna, obtained in Georgia, had an average of 0.771 µg/g and a range from 0.21 to 1.27 µg/g. This difference was statistically significant ($p = 0.03$).

As the data in **the Appendix** show, one can of *Chicken of the Sea* albacore had 0.338 µg/g mercury, but the other four cans averaged 0.585, 0.893, 0.923 and 1.118 µg/g. Those last three individual cans exceed the maximum reported for albacore in the FDA database. However, FDA uses a "composite" method: They mix lots of six cans together before analysis, yielding results that average multiple cans. This approach fosters broader sampling, but it obscures the variability of mercury levels in individual cans. If we had composited our five cans of *Chicken of the Sea* albacore, the result, 0.771 µg/g, would have been well within the range FDA has reported.

In short, our results for albacore, FDA data and other published data, all suggest that consumers who repeatedly choose canned albacore tuna may fairly frequently get mercury levels more than twice the FDA's average for the species, and sometimes as high as the levels typically found in swordfish.

**Table 3** lists samples identified as skipjack (the *Northeast* brand) separately from other light tuna. This brand had only 0.058 µg/g mercury, significantly less than in other light tuna ($p = 0.001$). However, most light tuna is likely to be skipjack, most of the time (Food News 2009). *Northeast* is probably not unique in this regard, but was the only brand we tested that declares its species content on the label.

Overall, our light tuna samples had slightly less mercury than FDA has historically reported. Whether this reflects merely our relatively small sample size or an actual recent trend toward lower mercury levels in light tuna is a question that might be pursued with more extensive testing.

**Country of Origin**. **Table 4 (page 9)** sorts our results by the country labeled as the source of the tuna in each set of samples. Since tuna are typically caught in international waters by fleets registered in many nations, country of origin generally indicates where the fish were processed. In recent years, the US companies that sell long-familiar American brands such as *StarKist*, *Chicken of the Sea* and *Bumble Bee* tuna have been sold to Asian companies, and most of the tuna consumed here is now imported from Southeast Asia, as reflected in the table.

One set of light tuna, *StarKist* obtained in North Carolina, contained tuna from Ecuador. Mercury levels in individual pouches varied, with 0.103, 0.125, 0.307, 0.330 and 0.405 µg/g (see full data in the Appendix). The last three averages are typical of what is found in yellowfin tuna (FDA 2012), and were the three highest levels among our 48 samples of light tuna. Of the 30 individual bites analyzed from Ecuador, 12 (40 percent) exceeded 0.25 µg/g (twice the overall average for light tuna), with a maximum value of 0.64 µg/g. Of our other 43 light tuna samples, only 11 of 258 bites analyzed (4.3 percent) exceeded 0.25 pm, and the maximum value was 0.31 µg/g.

Malsch and Muffett (2006) tested 75 cans of light tuna from Ecuador, Costa Rica and Mexico and found substantially higher mercury levels than in US-based brands. The overall mercury level in their samples was 0.405 µg/g, and those from Ecuador (18 cans) had the highest average,

## Table 4. Mercury in Tuna, by Country of Origin and Type

| Country of Origin | Tuna Type | No. of Samples | No. of Analyses | Average Hg, µg/g | Range, µg/g |
|---|---|---|---|---|---|
| Ecuador | Light | 5 | 30 | 0.254 | 0.05 - 0.64 |
| Indonesia | Albacore | 6 | 36 | 0.384 | 0.19 - 0.62 |
| Philippines | Light | 13 | 78 | 0.104 | 0.03 - 0.26 |
| Thailand | Light | 21 | 126 | 0.108 | 0.01 - 0.31 |
| Thailand | Albacore | 5 | 30 | 0.771 | 0.21 - 1.27 |
| United States | Light | 9 | 54 | 0.086 | 0.02 - 0.20 |

0.754 µg/g. Light tuna from Ecuador accounts for 8.5 percent of US tuna imports (NMFS 2011); our data suggest that it contains twice as much mercury as tuna from any other country from which our samples were imported, and three times as much mercury as our US-caught samples contained.

**Table 4** also displays the different mercury levels in our two sets of albacore samples, from Indonesia (*Ambrosia* brand) and Thailand (*Chicken of the Sea*). This difference was statistically significant ($p = 0.03$), but based on the few samples tested, we cannot conclude that it represents a real difference in mercury content of albacore from the two countries. It is more likely to reflect the natural variability of mercury levels in albacore tuna from the Southwest Pacific and/or Indian oceans.

We found no significant difference in mercury levels in light tunas from the Philippines and Thailand ($p = 0.86$). Average levels in samples from both countries were well below the long-term average reported by the FDA for light tuna. Thai samples had a somewhat more skewed distribution; 26 of 126 analyses (21 percent) had more than twice the average level of 0.108 µg/g, while only 6 of 78 analyses (7.7 percent) of Philippine samples exceeded twice that average of 0.104 µg/g.

Our 9 samples of US-caught light tuna (all *StarKist* pouches) had both a significantly lower average level than imported samples, 0.086 µg/g ($p = 0.02$) and a more uniform distribution; only one of 54 analyses (2 percent) had more than twice the average level. While our sample size was small, these data suggest that current mercury levels in US-caught tuna (i.e., caught by US-owned fleets, although often far from port, in the eastern tropical Pacific) may be somewhat lower than the levels historically measured by FDA, possibly as a consequence of overfishing (Ovetz 2006). If fish currently being caught are younger than in the past, that could result in a lower average mercury level.

**<u>Brand Differences</u>**: **Table 2** (page 6) shows our data by the brand and type of tuna tested. Since we tested only four to six samples of most brands, apparent differences among brands must be cautiously interpreted. In particular, further testing of the five smaller brands (*Ambrosia, Deep Blue, Empress, Northeast, World Horizons*) might not replicate the mercury levels we found. (However, since tuna is canned in large batches and most marketers obtain fish from the same sources over periods of time, it is reasonable to infer that our test results would apply to at least <u>some</u> other samples of each brand's product.) On the other hand, we tested larger numbers of samples of two major US brands, *StarKist* and *Chicken of the Sea*, and our results, shown in **Table 5**, support some interesting observatons.

These two familiar household staples accounted for 29 of 48 (60 percent) of our samples of light tuna. The small difference in overall average mercury levels in the two brands (0.126 µg/g for *Chicken of the Sea*, 0.131 µg/g for *StarKist*) was not statistically significant ($p = 0.17$). Each brand, though, had large differences in mercury levels in samples obtained in different places. *Chicken of the Sea* samples from California had 0.068 µg/g, well below average for all our light tuna samples, while *Chicken of the Sea* from Wisconsin had a much higher average, 0.184 µg/g. Three lots of our *StarKist* samples came in at 0.079, 0.088 and 0.093 µg/g, consistently below-average and with no individual bites with very high levels. But the fourth set—the tuna from Ecuador—had the highest average mercury level, 0.254 µg/g, and most of the highest individual values we found in any light tuna.


Based on our very limited sampling, it seems possible that a significant fraction of customers—including schools—who buy *StarKist* light tuna may get a product with triple the mercury level found in other lots of the same brand. That might be avoided if customers could elect not to buy tuna from Ecuador, but our experience suggests that the customer gets what the distributor has in stock, and neither party may have much control over the country of origin.

**Table 5. Mercury in Major US Brands of Light Tuna**

| Brand | Where Obtained | No. of Samples | No. of Analyses | Average Hg, µg/g | Range, µg/g |
|---|---|---|---|---|---|
| Chicken of the Sea | CA | 5 | 30 | 0.068 | 0.02 - 0.26 |
| | WI | 5 | 30 | 0.184 | 0.04 - 0.31 |
| | Combined | 10 | 60 | 0.126 | 0.02 - 0.31 |
| Star-Kist | FL | 5 | 30 | 0.088 | 0.04 - 0.13 |
| | MA | 4 | 24 | 0.093 | 0.03 - 0.20 |
| | NJ | 5 | 30 | 0.079 | 0.02 - 0.13 |
| | NC | 5 | 30 | 0.254 | 0.05 - 0.64 |
| | Combined | 19 | 114 | 0.131 | 0.02 - 0.64 |

Our *Chicken of the Sea* samples also varied widely in mercury levels. One batch had the second-lowest level we found in any light tuna; the other had the second highest average level, topped only by the *StarKist* samples from Ecuador. All 10 *Chicken of the Sea* light tuna samples came from Thailand. Differences between the product lots may simply reflect the inherent natural variability of light tuna.

Overall, our data suggest that whatever brand of light tuna a customer chooses, they seem likely to encounter significantly variable mercury levels.

## Risk Assessment

Fish consumption has well-documented nutritional benefits for fetal brain and visual development, and for cardiovascular health throughout life. Most experts advise women of childbearing age and children to eat fish, and choose low-mercury fish (IOM 2007, USDHHS 2010). The EPA/FDA advisory also suggests that children should eat "smaller portions" than adults, without specifying what "smaller" means (FDA 2004). Advice about mercury in seafood must be carefully crafted, lest it result in decreased fish consumption that could have counterproductive negative public-health impacts (Oken et al. 2003). Diverse approaches for meeting these competing objectives have been proposed (e.g., Groth 2010, Mahaffey et al. 2011, Stern and Korn 2011, WHO/FAO 2011, Teisl et al. 2011, Oken et al. 2012).

The incremental benefits of increasing fish consumption from a low to a moderate level appear to be much greater than the benefits of an increase from moderate to high consumption; i.e., an increase from less than one to about two fish meals per week has a substantial effect, but the benefits of further increases seem to plateau (FAO/WHO 2011). In contrast, the risk of neurodevelopmental effects of methylmercury exposure appears to increase in proportion to dose, across the full range of likely exposure (Mahaffey et al. 2011, Stern and Korn 2011, Bellinger 2012, Karagas et al. 2012).

Some analysts argue that since most Americans currently do not eat enough fish to benefit sufficiently, consumption of any seafood items for which benefits appear to outweigh risks should be encouraged (e.g., Mozaffarian and Rimm 2006). However, estimates of the absolute magnitudes of benefits and risks are subject to unavoidable uncertainties and are inevitably imprecise; ratios of the two estimates are even more so. Also, it is relatively easy to gain the benefits of fish consumption while minimizing the risk from mercury exposure, by choosing low-mercury fish. Many individual consumers would rather not accept avoidable risks that may arguably be smaller than the associated benefits, but would instead prefer to avoid those risks as much as possible, while still enjoying the benefits. This is perfectly rational behavior that deserves to be supported with expert guidance.

The primary strategy for managing the risks of methylmercury exposure is educating consumers to choose low-mercury varieties of fish and shellfish. In the context of this analysis, focused on children's consumption of canned tuna, there is a lower-mercury option (i.e., choosing light instead of albacore tuna). Our emphasis however, is on the relative risk of various tuna consumption scenarios, and on defining an acceptable level of risk, then using it to support guidance for schools and parents that will foster children's consumption of tuna while keeping their mercury exposure within safe limits.

Prenatal Developmental Toxicity.

Methylmercury was first linked to developmental neurotoxicity in severe pollution incidents in Minamata and Niigata, Japan and in an episode of grain contamination in Iraq (Harada 1995, Clarkson et al. 2003). Effects included irreversible brain damage, staggering gait, impaired vision, cognitive impairments, and many deaths. The same studies also revealed that the developing brain is particularly sensitive to methylmercury toxicity. Children whose mothers were exposed to mercury while they were pregnant generally suffered the most severe adverse effects.

In the 1980s researchers began studying whether much lower doses of methylmercury, i.e., exposure associated with ordinary fish consumption, could have similar although subtler effects on the developing nervous system. A study in New Zealand (Kjellstrom et al. 1986, 1989) assessed cognitive performance of children whose mothers ate a great deal of fish during pregnancy and found impaired performance in subjects with the highest prenatal mercury exposure; 52 percent of children in the high-mercury group had scores indicating delayed cognitive development, compared with 17 percent in the lower-mercury group. Two other large, well designed long-term studies of fish-eating island populations, each ongoing for more than 20 years, have provided much of the evidence on this question.

A study the Faeroe Islands, where the diet historically has included high-mercury pilot whale meat as well as fish, has consistently documented adverse effects on developing brain functions in children whose mothers had the highest methylmercury exposure during pregnancy. An assessment when the children were 7 years old (Grandjean et al. 1997) found adverse effects on attention, language, verbal memory and other cognitive functions, motor speed and eye-hand coordination. Each doubling of mercury exposure caused a seven-year-old child's overall performance to lag by 1.5 to 2 months relative to the norm for that age. A child whose blood mercury level was eight times (three doublings) higher than average was thus 4.5 to 6 months behind average, developmentally. The authors also expressed the effect of each doubling of exposure as a loss of about 1.5 IQ points.

A similar long-term epidemiological study in the Seychelles islands until recently had not associated adverse effects on children's cognitive development with their mothers' methylmercury exposure (e.g., Myers et al. 2003, Davidson et al. 2006), but later reports using improved statistical approaches (Myers et al. 2007) have noted adverse effects that are largely offset by, and were probably masked in previous analyses by, the beneficial effects on brain development of fish nutrients (Davidson et al. 2008).

The researchers in the Faeroes study applied similar improved analytical methods to account for confounding by maternal fish consumption in their study, and also noted that imprecise measures of exposure tended to bias their analysis toward underestimating effects of mercury. Corrections for the confounding and biases roughly doubled the estimated effects of mercury, per se (Budtz-Jørgensen et al. 2003, 2007).

Two recent studies using similar investigative and analytical strategies have assessed beneficial effects of maternal fish consumption and adverse effects of prenatal mercury exposure in American women with typical US fish consumption patterns and a normal range of methylmercury exposure. A study in Boston recorded maternal fish intake and hair and blood mercury levels in a cohort of pregnant women, and has examined the cognitive development of their children, testing at the ages of 6 months and 3 years for a variety of developmental measures (Oken et al. 2005, Oken et al. 2008). Women were sorted into two groups by fish intake: High consumers, who ate two or more fish meals per week (12 percent of participants), and everyone else.

And they were divided into two groups by mercury exposure: High exposure, with mercury levels above the 90$^{th}$ percentile (≥1.2 µg/g hair mercury), and everyone else.

Assessments of the children at both ages found beneficial effects of higher maternal fish consumption and adverse effects of higher prenatal mercury exposure. In three-year-olds, higher fish consumption by the mothers was associated with gains of 2.2 and 6.4 points on scores for the two primary tests used to measure cognitive development (each scored on a 100-point scale); higher mercury exposure was associated with deficits of 4.5 and 4.6 points on the same two scores (Oken et al. 2008).

Lederman et al. (2008) examined cognitive development in children born to a cohort of women in New York City. Umbilical-cord blood mercury level was measured at birth, and maternal fish consumption during pregnancy was recorded with a questionnaire. Children were evaluated at 1, 2, 3 and 4 years of age with tests for psychomotor and cognitive development, including IQ. Children born to mothers with high fish consumption scored better by 5.6 to 9.9 points (on a 100-point scale) on various indices of psychomotor development and intelligence. Children with higher cord-blood mercury scored lower by 2.9 to 4.2 points on the same tests; effects were most pronounced at age 4 years. Each doubling of cord-blood mercury was associated with a loss of about 2.5 IQ points. The authors estimated that a child with a very low blood mercury level, 0.1 µg/L, would have an IQ of 114, while one with a well-above-average blood mercury level of 7.74 µg/L would have an IQ of 99. No child in their study with a blood mercury level above 13 µg/L had an IQ greater than 100.

In the Boston study, the high-mercury women had hair mercury above the 90$^{th}$ percentile; i.e., adverse effects were observed in 10 percent of the study population. According to the NHANES surveys, women in the Northeast have somewhat higher fish consumption and blood and hair mercury levels than for the nation as a whole; the 90$^{th}$ percentile blood mercury level in this region is 5.2 µg/L (Mahaffey et al. 2009). The New York population had a geometric mean blood mercury level of 0.91 µg/L, virtually identical to the NHANES geometric mean of 0.92 µg/L (Lederman et al. 2008).

These recent studies have both confirmed the benefits of maternal fish consumption during pregnancy and measured adverse effects of prenatal methylmercury exposure at comparatively low doses. The current evidence does not identify a threshold for adverse effects; i.e., mercury doses across the range associated with ordinary amounts of fish consumption appear to have adverse effects. Overall, it is plausible that several percent of US newborn infants may suffer deficits equivalent to several IQ points because of prenatal methylmercury exposure. Because omega-3 fatty acid content and mercury content of fish are distributed differently (both in the seafood supply and in individual women's diets), adverse effects of mercury exposure are likely to be offset by cognitive benefits from fish nutrients in some, not all, children. The potential impact of mercury on cognitive development is a public-health concern of significant magnitude (Bellinger 2012) and warrants a focused, well reasoned risk management effort.

Effects of Methylmercury Exposure During Childhood. The primary focus of epidemiological studies on effects of methylmercury on the developing brain has been on prenatal exposure. Relatively few studies have assessed the possible adverse effects of mercury exposure and benefits of fish consumption by children as they are growing up.

The Faeroe Islands study took children's recent fish consumption into account as a possible confounding factor when testing for cognitive effects of prenatal mercury exposure, and found that the prenatal effect was predominant, primarily because the mother's exposure (including from pilot whale meat) was generally far higher than the children's own later exposure. However, in a follow-up study in 14-year-olds, the researchers measured the effect of mercury exposure on the transmission of auditory signals within the brain (Murata et al. 2004). In this case, the children's recent exposure, rather than their prenatal exposure, was associated with delays in signal transmission. This adverse effect was observed in children with a comparatively low hair mercury level, 1 μg/g.

The Seychelles study has produced several intriguing suggestions that elevated mercury exposure during childhood adversely affects cognitive functions. Myers et al. (2009) associated deficits in risk-taking, fine motor coordination and IQ in 9-year-olds with higher post-natal mercury exposure. Davidson et al. (2010) reported impaired performance on a year-end test in high-school children. Most recently, van Wijngaarden et al. (2011) tested 19-year-olds for six cognitive, psychological and neuromuscular functions and associated impaired performance on two measures in girls, and one in boys, with subjects' recent mercury exposure, measured as hair mercury. Exposure in this population is extraordinarily high; the mean hair level in the affected 19-year-olds was 10.3 μg/g.

A small study in Spain, where fish consumption is generally higher than in the US, assessed brain functions (general cognition, memory, motor and verbal development) in 4-year-old children with an average hair mercury level of 0.96 μg/g (Freire et al. 2010). Hair mercury levels were strongly correlated with children's fish consumption, and levels greater than 1 μg/g were associated with decrements of 6.6 points on general cognition, 8.4 points on memory and 7.5 points on verbal performance. The observed effects were net negative outcomes, over and above any beneficial effects of the children's fish consumption.

In addition to this small body of empirical evidence, there is an ample theoretical basis for concluding that adverse effects of childhood methylmercury exposure are likely. The human brain continues to grow and develop vigorously for several years after birth, and some brain functions are not fully formed until early adulthood. Periods of post-natal growth and development present "windows of opportunity" for potentially disruptive effects of toxic exposures. Because of their smaller body weights, children also get proportionally larger doses of contaminants than adults do who eat the same foods, and their metabolic detoxification and excretory mechanisms may be less effective than in adults, heightening the impact of absorbed doses (WHO 2010, ATSDR 2012).

Childhood exposure to other developmental neurotoxins, such as lead (Needleman et al. 1979, National Research Council 1980) and organophosphate insecticides (Bouchard et al. 2011, Eskenazi 2011), has been clearly shown to damage the developing brain, and it is reasonable to assume that childhood methylmercury exposure poses similar risks. While there may not yet be sufficient evidence to support robust dose-response estimates for children's everyday exposure, the risks for individual children who eat unusual amounts of fish are clearer.

Several relatively detailed case histories (documented in popular media accounts, not in peer-reviewed journal articles) have described clinically diagnosed methylmercury poisoning in children who ate large amounts of canned tuna. Three such cases are summarized in the sidebars on pages 16, 17 & 18. Children who eat this much fish are quite rare; they probably fall above the 99.99$^{th}$ percentile for their age group in fish consumption (i.e., less than 1 in 10,000 individuals). But rare is not nonexistent: there may be hundreds to thousands of such children, nationwide. Cases with overt clinical symptoms and blood mercury levels above 50 µg/L may be dramatic, but public health concerns should more sensibly focus on children with blood mercury levels above about 5 µg/L–roughly the 90$^{th}$ percentile in the NHANES survey—who are generally unlikely to exhibit overt clinical symptoms, but who may, based on recent evidence on prenatal exposure, be at risk for subtle effects on cognitive development.

Most research has examined effects on the developing brain, but methylmercury exposure may also adversely affect cardiovascular health (Roman et al. 2011) and the immune and endocrine systems (Gallagher and Meliker 2012, Gump et al. 2012), although research to explore these latter hazards is in its early stages. If research on mercury plays out as research on several other well studied toxic contaminants has, the rationale for minimizing children's methylmercury exposure while fostering beneficial fish consumption seems likely to grow progressively stronger as time passes.

Spikes vs. Chronic Exposure. The concept of "developmental windows" suggests that the timing of doses can be as critical as the magnitude of doses in determining whether adverse effects occur. In fact, this is a well established principle of toxicology; fetal development of mice and other experimental animals has been so well mapped out that experimenters can disrupt development of a particular function with great precision by administering a single dose of a toxic agent on a specific day during gestation. There is therefore no doubt that isolated exposure spikes have specific adverse effects, under experimental conditions. There is, in addition, ample evidence that human development includes comparable critical windows, not only during prenatal life and early childhood, but also during puberty and adolescence (Rice and Barone 2000, Selevan et al. 2000, Weiss 2000, ATSDR 2012).

However, direct evidence that transient high exposures to methylmercury have had specific adverse effects in humans is lacking. Children cannot be experimentally exposed to methylmercury spikes, and different individuals in a population of pregnant women will encounter exposure spikes (i.e., meals of high-mercury fish) at different times during gestation. If fetal development were affected, the specific developmental stages affected and behavioral outcomes associated with disrupting them would in all likelihood differ from person to person, obscuring meaningful patterns. Biomarkers used to quantify mercury exposure in studies documenting adverse effects of prenatal methylmercury exposure, blood and hair mercury levels, cannot reveal whether the observed adverse effects were associated with chronic, relatively constant exposure or with a few isolated spikes of elevated exposure punctuating periods of much lower exposure. These essentially unresolvable uncertainties are critical for developing risk-management strategies.

The 10 year-old boy was in the fifth grade when he started having problems in school. Although he had always been an outstanding student, he now couldn’t focus, struggled with simple tasks and missed assignments. He also began losing his physical coordination; his fingers curled, he developed tremors, and he could no longer hit a baseball or catch a football. He was examined by a physician who measured a blood mercury level of over 60 µg/L (the US average is around 1 µg/L) and diagnosed methylmercury poisoning. Starting about a year before his diagnosis, he had begun eating canned albacore tuna about twice a day. His parents had been pleased that he chose “brain food” over “junk food;” little did they know that his high-tuna diet contained about 12 times the federally defined maximum safe dose of mercury for his body weight. Once his mercury poisoning was recognized, he stopped eating tuna and has made a full recovery. (Sources: Waldman 2005, Anonymous 2008)

Estimating Acceptable Tuna Intakes for Children. The standard definition of “acceptable” exposure for toxic substances, used by national and international public health agencies, is a dose at which there is reasonable scientific certainty that no harm will occur. Particularly in situations where there are risk/benefit tradeoffs, as in this case, “acceptable risk” is a subjective societal value judgment and is clearly greater than “zero risk.” By long-standing convention, acceptable exposure has usually been defined as at least a factor of 10 below the lowest dose level known to have adverse effects, as a hedge against irreducible scientific uncertainties, primarily related to variability of individual susceptibility.

The 7-year-old-boy had developed normally through the age of three, when he began eating fish. The child simply loved fish and ate canned albacore tuna, tuna steaks and king mackerel virtually every day. Soon after he began this diet, his development slowed. He eventually stopped playing with other children and "sat lost in a fog," as his mother described it. He could not remember his classmates' names, could not express complete thoughts, lost motor skills and became physically uncoordinated. He was lethargic, had frequent stomach aches and reddened skin. A doctor finally diagnosed him with methylmercury poisoning based on a blood mercury level above 75 µg/L. He stopped eating fish, his blood mercury level declined, and his condition improved steadily. But neuropsychiatric testing revealed some irreversible brain damage. (Sources: Raines 2002, Hightower 2009)

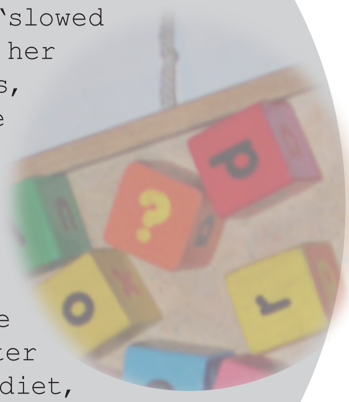
**Reference Dose**. In 2000 the US Environmental Protection Agency established a "Reference Dose" for methylmercury (US EPA 2000, Rice et al. 2003). A Reference Dose (abbreviated RfD) is a government definition of acceptable exposure. The RfD was based on evidence available at the time, which consisted primarily of the Faeroes study. The EPA began with a level of exposure that had a clear adverse effect in the Faeroes cohort, a blood mercury level of 58 µg/L, and divided that by 10, to take into account inter-individual variability and other scientific uncertainties, producing a reference blood level of 5.8 µg/L. EPA then used a pharmacokinetic model that relates blood mercury to dietary intake to set the RfD at 0.1 µg/kg/day, the dietary dose that corresponds to an equilibrium blood level of 5.8 µg/L.

The RfD was set several years before findings of the Boston and New York studies, described earlier, were available. Both of those studies, and other evidence discussed here, now suggest that prenatal mercury exposure has adverse effects in children born to women whose exposure was around or below the RfD, and recent studies have found no evidence of a threshold. In short, the RfD can no longer be comfortably regarded as a scientifically valid definition of acceptable exposure; some harm seems likely to occur in children whose exposure is around or even below the RfD.

How, then, can acceptable exposure be defined? Our approach rests on the fact that risks are relative, and generally speaking, proportional to dose. There is no "bright line" between "safe" and "unsafe" exposure, but a range of larger and smaller risks associated with larger and smaller doses. To support the analysis that follows, we specify six color-coded degrees of relative risk, centered on the RfD. Each step along the scale represents a doubling (or halving) of the mercury dose, as follows:

| Key to Color-Coded Relative Risk Levels | |
|---|---|
| 1 | **Safest**: Less than 0.25X RfD |
| 2 | **Close to Safe**: 0.25 to 0.5X RfD |
| 3 | **Borderline**: 0.5 to 1X RfD |
| 4 | **Some Risk**: 1 to 2X RfD |
| 5 | **More Risk**: 2 to 4X RfD |
| 6 | **Most Risky**: Over 4X RfD |

Doses from Levels 2 through 5 increase by 16-fold. The full range is far greater than that, since there is no minimum for Level 1 and no maximum for Level 6; illustrative doses presented below vary by 708-fold. Given the recent evidence of adverse effects at or below the RfD, we have defined doses between half the RfD and the RfD (Level 3) as "borderline;" i.e., doses in this range can neither be definitively labeled harmful nor presumed acceptably free of risk. This risk level is color-coded yellow in the table below. Level 2, In 2000, a 5-year-old girl suddenly stopped learning. She had been an early walker and talker, and her parents, both accomplished writers, were justifiably proud of their obviously bright child. But suddenly she "slowed down." She forgot how to tie her shoes, could not remember words, and her hair stopped growing. She loved tuna fish sandwiches, and her parents, unaware of its high mercury content, were feeding her about two cans of albacore tuna per week. She had a blood mercury level of 13 μg/L, far above normal. Within a few months after tuna was eliminated from her diet, She had a "huge developmental surge," as her mother described it. As her blood mercury level came down into the normal range, her verbal and physical abilities returned. (Sources: Raines 2002, Roe and Hawthorne 2005)



0.25 to 0.5X the RfD, color coded green, is safer but offers a possibly insufficient margin of uncertainty of only 2- to 4-fold below doses that may have adverse effects. Level 1, doses less than 0.25X the RfD, color coded blue, has an uncertainty margin of at least 4X. While this is still narrow compared to the conventional 10X margin, it is probably not feasible to reduce the mercury exposure of a majority of children much below this level without reducing seafood consumption to a degree that would have substantial negative public health consequences. We have therefore defined doses of less than 0.25X the RfD as the "acceptable" level of risk in this analysis.

At the other end of the spectrum, exposure at 1 to 4X the RfD (Levels 4 and 5, color coded orange and pink, respectively) can now be presumed to have at least subtle adverse effects, with both the likelihood and the possible seriousness of adverse effects increasing as dose increases. In our judgment, doses that exceed the RfD by more than 4X (Level 6, color coded red) seem likely to pose a significant risk of damage to cognitive development and should be avoided if at all possible.

Relative Risk Scenarios. The risks of tuna consumption for any given child depend on multiple variables: The type of tuna, the average mercury level in the tuna, the period of time over which the tuna is consumed, the child's body weight, the child's developmental status, and assorted personal traits that may affect individual susceptibility. We have modeled consumption scenarios using different values for most of these variables, and compared the resulting doses with the risk levels outlined above.

We present a few illustrative examples, chosen from a far larger array of possible combinations. The examples consider children with weights of 20, 35 and 50 kg (44, 77 and 110 pounds, equivalent to 6-, 10- and 14-year olds), who eat either 57 or 170 grams (2 or 6 ounces, "low" and "high" consumption rates representing about 1 to 3 servings) of light tuna containing 0.150 μg/g mercury, or albacore tuna with 0.500 μg/g. These mercury levels are in the middle of the ranges we found in our tests, although somewhat above the averages for each tuna type. We calculate the doses that result when exposure is averaged over one month, one week or one day, and compare them to the RfD and to our relative risk levels, defined above. Results are shown in **Table 6** on the next page.

When exposure is averaged over one month, shown in the upper section of Table 6, most doses in these examples fall into Risk Levels

## Table 6. Relative Risk of Selected Tuna Consumption Scenarios

| Child's Weight | Tuna Hg, µg/g | Amount eaten, g | Hg dose, µg | Hg dose, µg/kg | Dose as % of RfD | Risk Level |
|---|---|---|---|---|---|---|
| | | Exposure Averaged over 1 Month | | | | |
| 20 kg | 0.150 | 57 | 8.5 | 0.43 | 14 | 1 |
| | | 170 | 25.5 | 1.28 | 43 | 2 |
| | 0.500 | 57 | 28.4 | 1.42 | 47 | 2 |
| | | 170 | 85.1 | 4.26 | 142 | 4 |
| 35 kg | 0.150 | 57 | 8.5 | 0.24 | 8 | 1 |
| | | 170 | 25.5 | 0.73 | 24 | 1 |
| | 0.500 | 57 | 28.4 | 0.81 | 27 | 2 |
| | | 170 | 85.1 | 2.43 | 81 | 3 |
| 50 kg | 0.150 | 57 | 8.5 | 0.17 | 6 | 1 |
| | | 170 | 25.5 | 0.51 | 17 | 1 |
| | 0.500 | 57 | 28.4 | 0.57 | 19 | 1 |
| | | 170 | 85.1 | 1.70 | 57 | 3 |
| | | Exposure Averaged over 1 Week | | | | |
| 20 kg | 0.150 | 57 | 8.5 | 0.43 | 61 | 3 |
| | | 170 | 25.5 | 1.28 | 182 | 4 |
| | 0.500 | 57 | 28.4 | 1.42 | 203 | 5 |
| | | 170 | 85.1 | 4.26 | 608 | 6 |
| 35 kg | 0.150 | 57 | 8.5 | 0.24 | 35 | 2 |
| | | 170 | 25.5 | 0.73 | 104 | 4 |
| | 0.500 | 57 | 28.4 | 0.81 | 116 | 4 |
| | | 170 | 85.1 | 2.43 | 347 | 5 |
| 50 kg | 0.150 | 57 | 8.5 | 0.17 | 24 | 1 |
| | | 170 | 25.5 | 0.51 | 73 | 3 |
| | 0.500 | 57 | 28.4 | 0.57 | 81 | 3 |
| | | 170 | 85.1 | 1.70 | 243 | 5 |
| | | Exposure Averaged over 1 Day | | | | |
| 20 kg | 0.150 | 57 | 8.5 | 0.43 | 425 | 6 |
| | | 170 | 25.5 | 1.28 | 1275 | 6 |
| | 0.500 | 57 | 28.4 | 1.42 | 1420 | 6 |
| | | 170 | 85.1 | 4.26 | 4250 | 6 |
| 35 kg | 0.150 | 57 | 8.5 | 0.24 | 243 | 5 |
| | | 170 | 25.5 | 0.73 | 729 | 6 |
| | 0.500 | 57 | 28.4 | 0.81 | 811 | 6 |
| | | 170 | 85.1 | 2.43 | 2431 | 6 |
| 50 kg | 0.150 | 57 | 8.5 | 0.17 | 170 | 4 |
| | | 170 | 25.5 | 0.51 | 510 | 6 |
| | 0.500 | 57 | 28.4 | 0.57 | 568 | 6 |
| | | 170 | 85.1 | 1.70 | 1702 | 6 |

1 **Safest:** Less than 25% of the RfD

2 **Close to Safe:** 25 to 50% of the RfD

3 **Borderline:** 50 to 100% of the RfD

4 **Some Risk:** 100 to 200% (i.e., 1 to 2 times) the RfD

5 **More Risk:** 2 to 4 times the RfD

6 **Most Risky:** More than 4 times the RfD (with no upper limit)

1 or 2 (blue or green). The exceptions involve children with smaller body weights who eat larger than average amounts of tuna and/or tuna with especially high mercury levels (i.e., albacore); risks in those cases can rise to Level 3 or Level 4 (yellow and orange).

The upper portion of Table 6 applies to most children. According to government and industry data, the average American eats 2.7 pounds (1,226 g) of canned tuna a year, about three-quarters of it light tuna. These are gross per capita consumption data; age-specific estimates of children's consumption are not available. If we reasonably assume, however, that an average child is similar to an average American in this respect, 1,226 g/year translates to 3.36 g/day, 23.5 g/week, or 101 g/month. The latter figure is roughly in the middle of the range (57 to 170 g/month) illustrated by our examples of monthly intake. The examples shown here suggest that most children can eat light tuna containing 0.150 µg/g mercury up to twice a month without exceeding our conservative definition of acceptable risk. The examples also suggest, though, that smaller children should probably be limited to just one serving per month, and that albacore tuna contains too much mercury for most children.

When exposure is averaged over 1 week (the middle section of Table 6), relative doses are roughly four times higher than with averaging over a month, and Risk Levels span the full range from Level 1 to Level 6. Relatively few children eat as much tuna as the examples in this section suggest. Food intake surveys indicate that less than 10 percent of US adults eat seafood twice a week or more (FDA 2009); in the absence of adequate child-specific surveys, we assume that children's consumption patterns are similar. Nevertheless, some children love tuna and will eat it as often as it is offered to them. The examples here indicate that, except for the largest children (50 kg or 110 lb about average for a 14-year-old) eating two ounces of light tuna a week, such "tuna loving" children get too much mercury. Children who eat larger amounts (6 ounces a week) of light tuna, or any amounts of albacore tuna each week, get doses that approach or exceed the RfD. The examples suggest that small children should eat tuna less than weekly, that older children can safely eat one small serving of light tuna per week but should be discouraged from eating it more often, and that children who eat tuna weekly should not be given albacore.

The lower section of Table 6 repeats the same consumption scenarios as in the sections above, but averages doses over a single day. Even the smallest consumption rate here (57 g/day) probably falls above the 99.99th percentile for children's seafood intake; i.e., the number of children who actually eat this much tuna is extremely small (although that still may amount to hundreds or thousands of individuals, nationwide). As the Risk Levels shown here indicate, it is fortunate that such exposures are rare, because the doses range from 1.7 to 42.5 times the RfD.

However, this section of Table 6 also represents the actual mercury dose a child gets on the day the tuna is consumed. In this sense, every child who eats tuna is exposed to a brief (24-hour average) exposure spike with the Risk Levels indicated in the table. These examples illustrate the magnitude of peak exposures involved, which needs to be considered in efforts to assess the risks of children's mercury exposure; both the size and timing may be critical.

## Discussion

Our tests of tuna served in schools produced no suggestion that tuna from this market sector differs in mercury content in any important ways from canned tuna sold in supermarkets. Our overall average of 0.118 µg/g mercury in light tuna was consistent with FDA's slightly higher average for this product category, but even our limited sampling illustrates how variable the mercury content of light tuna is. Our tests of albacore tuna, only 11 samples, found an average of 0.560 µg/g mercury, much higher than FDA has reported, but our results are consistent with several other independent test reports. Our albacore samples also showed highly variable mercury levels.

The variability of mercury levels in tuna needs to be taken into account in risk assessments. We tested three different "bites" from each individual package, and sometimes found mercury levels that varied by 5- to 10-fold in a single package. This suggests that different children eating the same meal in the same school on the same day might get mercury doses that could vary by as much as an order of magnitude. This aspect is most significant when trying to assess the importance of brief peaks of exposure for children's overall risk from eating tuna.

Our samples of tuna from Ecuador had by far the highest average mercury level we found in light tuna, as had been previously reported (Malsch and Muffett 2006). This difference, and the higher mercury levels in tuna from Latin American countries in general, should be explored with more extensive testing, and efforts should be made to understand why mercury levels in this market sector are so high, and whether anything can be done to reduce them. More work is also needed to try to determine why most independent testers have found significantly higher mercury levels in canned albacore tuna than FDA's tests have detected (the weighted average found in 370 samples tested by four other research groups is 0.516 µg/g, versus FDA's average of 0.350 µg/g in 451 samples.) Dialogue between FDA and other investigators might focus on resolving this question.

The mercury levels we used in the dose calculations in Table 6, 0.150 µg/g for light tuna and 0.500 µg/g for albacore, are slightly above the FDA averages, an element of conservatism in our risk estimates. However, our tests and other reports have found levels above 0.300 µg/g in light tuna and above 1.00 µg/g in albacore. In other words, the examples in Table 6 are not even close to realistic "worst case" scenarios; some children who eat tuna will get doses far higher than our scenarios indicate.

Our testing provides only a limited basis for consumer guidance. Other than confirming that albacore tuna has much higher mercury levels than light tuna, and supporting advice to avoid buying tuna labeled as product of Ecuador and other Latin American countries if possible, our sampling does not suggest that country of origin or product brand can reliably be used to reduce mercury exposure.

Risk-management strategies require a definition of an "acceptable" risk level, and we have provided ours, defining acceptable risk as mercury exposure below 25 percent of the current US Reference Dose. That subjective

judgment combines three considerations: (1) The desire for a fairly substantial margin of exposure below the lowest dose known to have adverse effects (currently near or slightly below the RfD), to account for known and unknown inter-individual variables that affect risk; (2) Balancing risks against the nutritional benefits of fish consumption by children; and (3) A concession to practicality, since reducing exposure much below 25 percent of the RfD would probably be very difficult to achieve without undesirable decreases in seafood consumption. Others may differ with our judgment, and we look forward to wider discussion of this important, value-laden question, the acceptable degree of risk of harm to children's developing cognitive abilities.

Our conclusion that occasional consumption of tuna is probably safe for most children rests on the assumption that the risk can be accurately assessed by averaging exposure over periods of a week or a month. However, it is far from clear scientifically that this is the most appropriate assumption. Ample evidence from animal studies shows that transient high exposures have lasting adverse effects, if they occur during sensitive "developmental windows."

It is not known whether such exposure spikes have had lasting adverse effects in humans, but we know of no scientific basis for asserting that exposure spikes could not be harmful. In the context of those irresolvable uncertainties, the magnitude of spikes involved—i.e., the 24-hour average doses shown in Table 6—deserves to be given weight in risk management. While we do not believe the uncertain risks of spike exposures should outweigh the known benefits of seafood consumption, awareness that these spikes can exceed 10 times the RfD in many cases (5 of 12 examples in Table 6) might reasonably tilt the balance toward precaution, especially where the risks are least ambiguous, if not obviously unacceptable. In particular, in responding to children who eat more than average amounts of tuna, we think the possibility of harm from exposure spikes justifies greater efforts to minimize risks.

The main reason nutrition experts encourage all of us—including children—to eat fish is that seafood contains omega-3 fatty acids, which benefit both prenatal nervous system development and lifelong cardiovascular health. But many kinds of seafood and some plants provide omega-3s, generally with far less mercury than tuna contains. It is important that children be offered a variety of other seafood items, such as salmon, scallops, shrimp or sardines, and not just tuna.

**Table 7 (page 23)** summarizes the omega-3 fatty acid and mercury content of a variety of popular fish and shellfish choices. Species vary almost as widely in omega-3 content as they do in mercury content. Omega-3 values in the table are expressed in milligrams per gram (mg/g), and the table also shows ratios, as mg of omega-3s per µg of mercury. Albacore tuna contains a moderately high level of omega-3s, but is also very high in mercury. Two species of light tuna, skipjack and yellowfin, have far less omega-3 content, and yellowfin (based on recent FDA data) has mercury content comparable to albacore.

As the right-hand column shows, benefit/risk ratios for all tuna types are quite low. Salmon, anchovies and scallops each provide about 50 times more omega-3s per unit of mercury than even the best kind of tuna does. (Several fish varieties with even higher mercury levels than tuna, and similarly unfavorable benefit/risk ratios, such as swordfish and grouper, are not included in this table.)

If our recommended limits on children's tuna consumption, outlined below, were universally adopted and followed, we believe the economic consequences would be mild and possibly beneficial. If as we surmise the average child currently eats about 100 g of tuna per month, our suggested limit of two servings per month for most children would not decrease total consumption (and in fact might allow some increase.) Limiting consumption among children who would otherwise eat tuna too frequently should have a very minor economic impact. If schools and parents offer children other varieties of seafood, overall consumption of fish and shellfish should grow, with long-term economic and public-health benefits. Substitution of other seafood choices for tuna in the school lunch program should not be difficult, as many companies that currently provide canned tuna to schools also offer other seafood. For example, Chicken of the Sea even advertizes its salmon product on the label of its tuna pouches.


**Table 7. Omega-3 and Mercury Content of Tuna Varieties and Selected Other Seafood Choices**

| Seafood Item | Omega-3s, mg/g | Mercury, µg/g | Ratio, mg omega-3s/ µg Hg |
|---|---|---|---|
| **Tuna Varieties** | | | |
| Albacore | 8.62 | 0.350 | 25 |
| Skipjack | 2.70 | 0.128 | 21 |
| Yellowfin | 0.40 | 0.354 | 1 |
| **High Omega-3, Low Hg Choices** | | | |
| Anchovies | 20.55 | 0.017 | 1209 |
| Herring | 20.14 | 0.084 | 240 |
| Mackerel, Atlantic | 12.03 | 0.050 | 241 |
| Salmon, Wild | 10.43 | 0.022 | 474 |
| Salmon, Farmed | 26.48 | 0.022 | 1204 |
| Sardines | 9.82 | 0.013 | 755 |
| Trout, Freshwater | 9.35 | 0.071 | 132 |
| **Other Lower-Mercury Choices** | | | |
| Catfish | 1.77 | 0.025 | 71 |
| Clams | 2.84 | 0.009 | 316 |
| Cod | 1.58 | 0.111 | 14 |
| Crab | 4.13 | 0.065 | 63 |
| Flatfish (Flounder, Plaice, Sole) | 3.66 | 0.056 | 65 |
| Lobster, American | 0.84 | 0.107 | 8 |
| Mussels | 7.82 | 0.009 | 869 |
| Oysters | 6.88 | 0.012 | 573 |
| Pollock | 4.68 | 0.031 | 151 |
| Scallops | 3.65 | 0.003 | 1216 |
| Shrimp/prawns | 3.15 | 0.009 | 350 |
| Tilapia | 1.90 | 0.013 | 146 |

Hg data from US FDA; omega-3 data from Mozaffarian & Rimm 2006 and WHO/FAO 2011

## Recommendations

**(1) Children should not eat albacore tuna.** While Table 6 suggests that older children may occasionally have small servings of albacore without undue risk, much of the albacore on the market contains more mercury than the level we used in our scenarios. For smaller children, even an occasional albacore meal pushes doses into the unacceptable range. There is no particular benefit associated with albacore to justify tripling a child's mercury dose. Some albacore samples have mercury levels as high as those in swordfish. FDA and EPA include swordfish on a "do not eat" list for women of childbearing age and young children; for children at least, albacore tuna belongs on that list.

**(2) Parents and schools should develop strategies to keep most children's mercury doses within Risk Level 1, most of the time, by limiting their consumption to six ounces of light tuna per month.** While occasional excursions into Levels 2 or 3 are not reason to panic, keeping a child's long-term average exposure at less than 25 percent of the RfD is probably the soundest way to keep the risk of harm at an acceptable level.

**(3) Schools and parents need to be alert for situations in which a more conservative risk management approach is required.** For instance:

- Smaller children (less than 25 kg/55 lbs) should not eat light tuna more than once a month.
- Children of any age who "love tuna," and will eat it as often as they can, are at the greatest risk for getting mercury doses that pose unacceptable risks. To avoid excessive exposure among frequent eaters, schools should serve tuna no more than twice a month.
- No child should ever be allowed to eat tuna every day, and most children who eat tuna once a week will also get excessive mercury doses. As in (2) above, even tuna-loving children should be limited to 6 ounces per month.
- Adults should also be alert for children who eat larger-than-average (more than 2 to 3 ounces) portions of tuna.
- Parents of children who eat tuna once a week or more should have the child's blood tested for mercury. If the result is higher than 5 μg/L, the child's tuna consumption should be restricted and low-mercury seafood items should be substituted in the diet.

**(4) Parents and school officials should coordinate their risk-management efforts,** since a child's tuna consumption is the sum of what occurs at home, in school and in other places.

**(5) Fact sheets should be prepared and distributed** about mercury exposure, the health risks it poses, the nutritional benefits of fish consumption, the importance of tuna as a mercury exposure source, and strategies for managing exposure. Such information could be used for communicating with students and parents, and perhaps for a teaching unit on an environmental health topic.

**(6) Schools should try to avoid purchasing tuna imported from Ecuador and other Latin American fisheries**, by specifying to suppliers that they want tuna caught by US fleets or imported from Asia.

**(7) Parents, schools and other caregivers should offer children a greater variety of seafood choices (see Table 7), instead of tuna, for many of their seafood meals.**

**(8) The USDA Child Nutrition Program should phase out subsidies for canned tuna.** Canned tuna is by far the largest source of US children's exposure to methylmercury, and some children's overall exposure and risk is clearly too high. It makes no sense for taxpayers to subsidize any part of this risk. USDA should explore avenues for including a wider variety of seafood items, and in particular, items with more favorable omega-3-to-mercury ratios than tuna, in the subsidized program. The School Lunch Program should also coordinate these efforts with the USDA team that updates the Dietary Guidelines for Americans, to ensure that sound advice about children's tuna consumption is included in the next edition of the Guidelines.

**(9) The EPA and FDA need to proceed expeditiously with updating their assessment of the benefits and risks of seafood consumption, and their joint consumer Advisory on mercury in seafood.** Specific advice on managing children's methylmercury exposure should be an expanded part of the new Advisory. Canned light tuna, currently listed and recommended as a "low-mercury" choice in the Advisory, is no such thing and should not be so listed. The EPA also needs to update the RfD for methylmercury, to take into account research findings of the past decade.

**(10) More research on mercury exposure and its effects on cognitive development during childhood is needed.** Studies might identify children who eat above-average amounts of fish, measure their mercury exposure, and assess the positive nutritional and adverse mercury effects on their developing brain functions, by comparison with children who eat little or no fish.

**(11) The research community needs to develop a better theoretical and empirical basis for assessing the risks of spike exposures, and to engage in dialogue with policymakers concerning how to account for them in carrying out risk assessments.** Uncertainties about spike exposures impose severe limits on the ability of risk assessors to estimate the possible effects of childhood mercury exposure; a concerted effort is needed to reduce those uncertainties.

**(12) FDA needs to engage in a dialogue with other analysts** who have tested mercury levels in albacore tuna to explore why FDA's reported levels are so much lower than those consistently found by other investigators. This disparity is puzzling and needs to be addressed.

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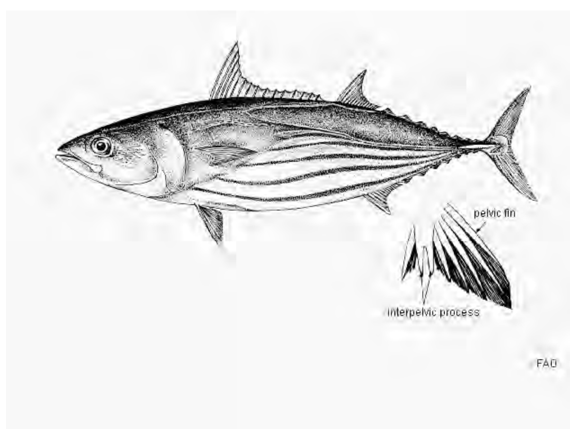

## APPENDIX - TUNA SAMPLE CHARACTERISTICS AND COMPLETE TEST RESULTS

| State | Package Type | Brand Name and Product Description | Country of Origin | Hg, µg/g | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | A | B | C | D | E | F | Average |
| **CA** (First Set) | 66.5 oz can | Deep Blue Chunk Light Tuna in Water | Philippines | 0.18 | 0.15 | 0.08 | 0.12 | 0.15 | 0.16 | 0.140 |
| | 66.5 oz can | Deep Blue Chunk Light Tuna in Water | Philippines | 0.14 | 0.16 | 0.16 | 0.19 | 0.19 | 0.18 | 0.170 |
| | 66.5 oz can | Deep Blue Chunk Light Tuna in Water | Philippines | 0.05 | 0.04 | 0.03 | 0.05 | 0.08 | 0.08 | 0.055 |
| | 66.5 oz can | Deep Blue Chunk Light Tuna in Water | Philippines | 0.11 | 0.09 | 0.14 | 0.15 | 0.13 | 0.15 | 0.128 |
| | 66.5 oz can | Deep Blue Chunk Light Tuna in Water | Philippines | 0.06 | 0.07 | 0.08 | 0.07 | 0.05 | 0.04 | 0.062 |
| **CA** (Second Set) | 43 oz foil pouch | Chicken of the Sea Premium Wild-Caught Light Tuna in Water | Thailand | 0.03 | 0.03 | 0.05 | 0.07 | 0.10 | 0.10 | 0.063 |
| | 43 oz foil pouch | Chicken of the Sea Premium Wild-Caught Light Tuna in Water | Thailand | 0.07 | 0.06 | 0.06 | 0.04 | 0.06 | 0.07 | 0.060 |
| | 43 oz foil pouch | Chicken of the Sea Premium Wild-Caught Light Tuna in Water | Thailand | 0.24 | 0.26 | 0.08 | 0.07 | 0.05 | 0.05 | 0.125 |
| | 43 oz foil pouch | Chicken of the Sea Premium Wild-Caught Light Tuna in Water | Thailand | 0.02 | 0.02 | 0.07 | 0.05 | 0.08 | 0.10 | 0.057 |
| | 43 oz foil pouch | Chicken of the Sea Premium Wild-Caught Light Tuna in Water | Thailand | 0.04 | 0.04 | 0.03 | 0.04 | 0.03 | 0.02 | 0.033 |

| APPENDIX (Cont.) TUNA SAMPLE CHARACTERISTICS AND COMPLETE TEST RESULTS | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| State | Package Type | Brand Name and Product Description | Country of Origin | Hg, µg/g | | | | | | |
| | | | | A | B | C | D | E | F | Average |
| FL | 66.5 oz can | Star Kist Chunk Light Tuna in water | Thailand | 0.07 | 0.11 | 0.10 | 0.08 | 0.08 | 0.12 | 0.093 |
| | 66.5 oz can | Star Kist Chunk Light Tuna in water | Thailand | 0.11 | 0.10 | 0.11 | 0.11 | 0.09 | 0.11 | 0.105 |
| | 66.5 oz can | Star Kist Chunk Light Tuna in water | Thailand | 0.08 | 0.09 | 0.07 | 0.11 | 0.06 | 0.04 | 0.075 |
| | 66.5 oz can | Star Kist Chunk Light Tuna in water | Thailand | 0.09 | 0.13 | 0.11 | 0.12 | 0.11 | 0.10 | 0.110 |
| | 66.5 oz can | Star Kist Chunk Light Tuna in water | Thailand | 0.04 | 0.06 | 0.05 | 0.06 | 0.08 | 0.06 | 0.058 |
| GA | 66.5 oz can | Chicken of the Sea Solid White Albacore Tuna in Water | Thailand | 0.94 | 0.99 | 1.10 | 1.15 | 1.26 | 1.27 | 1.118 |
| | 66.5 oz can | Chicken of the Sea Solid White Albacore Tuna in Water | Thailand | 0.85 | 0.87 | 0.94 | 0.93 | 0.91 | 0.86 | 0.893 |
| | 66.5 oz can | Chicken of the Sea Solid White Albacore Tuna in Water | Thailand | 0.37 | 0.38 | 0.21 | 0.22 | 0.41 | 0.43 | 0.338 |
| | 66.5 oz can | Chicken of the Sea Solid White Albacore Tuna in Water | Thailand | 0.97 | 0.98 | 0.92 | 0.96 | 0.85 | 0.86 | 0.923 |
| | 66.5 oz can | Chicken of the Sea Solid White Albacore Tuna in Water | Thailand | 0.31 | 0.29 | 0.76 | 0.74 | 0.73 | 0.68 | 0.585 |

| APPENDIX (Cont.) TUNA SAMPLE CHARACTERISTICS AND COMPLETE TEST RESULTS | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **State** | **Package Type** | **Brand Name and Product Description** | **Country of Origin** | **Hg, µg/g** | | | | | | |
| | | | | A | B | C | D | E | F | Average |
| | | | | | | | | | | |
| **IL** | 66.5 oz can | Empress Chunk Light Tuna in water | Philippines | 0.07 | 0.04 | 0.04 | 0.08 | 0.05 | 0.04 | 0.053 |
| | 66.5 oz can | Empress Chunk Light Tuna in water | Philippines | 0.09 | 0.08 | 0.13 | 0.10 | 0.09 | 0.08 | 0.095 |
| | 66.5 oz can | Empress Chunk Light Tuna in water | Philippines | 0.09 | 0.11 | 0.08 | 0.11 | 0.10 | 0.12 | 0.102 |
| | 66.5 oz can | Empress Chunk Light Tuna in water | Philippines | 0.13 | 0.16 | 0.21 | 0.26 | 0.14 | 0.15 | 0.178 |
| | 66.5 oz can | Empress Chunk Light Tuna in water | Philippines | 0.07 | 0.11 | 0.11 | 0.11 | 0.22 | 0.22 | 0.140 |
| | | | | | | | | | | |
| **ME** | 66.5 oz can | World Horizons Chunk Light Tuna in water | Philippines | 0.08 | 0.10 | 0.04 | 0.05 | 0.08 | 0.08 | 0.072 |
| | 66.5 oz can | World Horizons Chunk Light Tuna in water | Philippines | 0.03 | 0.05 | 0.07 | 0.05 | 0.03 | 0.05 | 0.047 |
| | 66.5 oz can | World Horizons Chunk Light Tuna in water | Philippines | 0.04 | 0.04 | 0.08 | 0.05 | 0.23 | 0.23 | 0.112 |
| | 66.5 oz can | World Horizons Chunk Light Tuna in water | Thailand | 0.31 | 0.28 | 0.30 | 0.24 | 0.27 | 0.23 | 0.272 |

| APPENDIX (Cont.) TUNA SAMPLE CHARACTERISTICS AND COMPLETE TEST RESULTS | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| State | Package Type | Brand Name and Product Description | Country of Origin | Hg, µg/g | | | | | | |
| | | | | A | B | C | D | E | F | Average |
| | | | | | | | | | | |
| **MA** | 43-oz foil pouch | StarKist Chunk Light Tuna in water | Not stated (USA) | 0.08 | 0.12 | 0.08 | 0.12 | 0.17 | 0.11 | 0.113 |
| | 43-oz foil pouch | StarKist Chunk Light Tuna in water | Not stated (USA) | 0.10 | 0.09 | 0.07 | 0.13 | 0.05 | 0.03 | 0.078 |
| | 43-oz foil pouch | StarKist Chunk Light Tuna in water | Not stated (USA) | 0.04 | 0.09 | 0.10 | 0.05 | 0.09 | 0.09 | 0.077 |
| | 43-oz foil pouch | StarKist Chunk Light Tuna in water | Not stated (USA) | 0.03 | 0.04 | 0.10 | 0.10 | 0.09 | 0.06 | 0.070 |
| | 43-oz foil pouch | StarKist Chunk Light Tuna in water | Not stated (USA) | 0.08 | 0.12 | 0.16 | 0.20 | 0.08 | 0.11 | 0.125 |
| | | | | | | | | | | |
| **NJ** | 43-oz foil pouch | StarKist Chunk Light Tuna in water | Not stated (USA) | 0.11 | 0.11 | 0.10 | 0.13 | 0.09 | 0.11 | 0.108 |
| | 43-oz foil pouch | StarKist Chunk Light Tuna in water | Not stated (USA) | 0.09 | 0.1 | 0.08 | 0.07 | 0.07 | 0.09 | 0.083 |
| | 43-oz foil pouch | StarKist Chunk Light Tuna in water | Not stated (USA) | 0.02 | 0.04 | 0.02 | 0.08 | 0.02 | 0.08 | 0.043 |
| | 43-oz foil pouch | StarKist Chunk Light Tuna in water | Not stated (USA) | 0.09 | 0.09 | 0.08 | 0.08 | 0.06 | 0.08 | 0.080 |

## APPENDIX (Cont.) TUNA SAMPLE CHARACTERISTICS AND COMPLETE TEST RESULTS

| State | Package Type | Brand Name and Product Description | Country of Origin | Hg, µg/g | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | A | B | C | D | E | F | Average |
| **NY** | 66.5 oz can | Northeast Chunk Light Skipjack Tuna in Water | Thailand | 0.21 | 0.21 | 0.07 | 0.08 | 0.02 | 0.01 | 0.100 |
| | 66.5 oz can | Northeast Chunk Light Skipjack Tuna in Water | Thailand | 0.07 | 0.04 | 0.01 | 0.01 | 0.07 | 0.10 | 0.050 |
| | 66.5 oz can | Northeast Chunk Light Skipjack Tuna in Water | Thailand | 0.04 | 0.02 | 0.01 | 0.01 | 0.10 | 0.13 | 0.052 |
| | 66.5 oz can | Northeast Chunk Light Skipjack Tuna in Water | Thailand | 0.03 | 0.02 | 0.02 | 0.03 | 0.04 | 0.04 | 0.030 |
| | 66.5 oz can | Northeast Chunk Light Skipjack Tuna in Water | Thailand | 0.03 | 0.02 | 0.07 | 0.03 | 0.10 | 0.10 | 0.058 |
| **NC** | 43-oz foil pouch | StarKist Chunk Light Tuna in Water | Ecuador | 0.48 | 0.46 | 0.19 | 0.21 | 0.55 | 0.54 | 0.405 |
| | 43-oz foil pouch | StarKist Chunk Light Tuna in Water | Ecuador | 0.05 | 0.07 | 0.23 | 0.28 | 0.07 | 0.05 | 0.125 |
| | 43-oz foil pouch | StarKist Chunk Light Tuna in Water | Ecuador | 0.64 | 0.61 | 0.24 | 0.21 | 0.13 | 0.15 | 0.330 |
| | 43-oz foil pouch | StarKist Chunk Light Tuna in Water | Ecuador | 0.13 | 0.12 | 0.09 | 0.10 | 0.08 | 0.10 | 0.103 |
| | 43-oz foil pouch | StarKist Chunk Light Tuna in Water | Ecuador | 0.26 | 0.27 | 0.41 | 0.38 | 0.25 | 0.27 | 0.307 |

| APPENDIX (Cont.) TUNA SAMPLE CHARACTERISTICS AND COMPLETE TEST RESULTS | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| State | Package Type | Brand Name and Product Description | Country of Origin | Hg, µg/g | | | | | | |
| | | | | A | B | C | D | E | F | Average |
| VT | 66.5-oz can | Ambrosia White Chunk Albacore Tuna in Water | Indonesia | 0.48 | 0.41 | 0.34 | 0.33 | 0.36 | 0.40 | 0.387 |
| | 66.5-oz can | Ambrosia White Chunk Albacore Tuna in Water | Indonesia | 0.46 | 0.47 | 0.33 | 0.33 | 0.40 | 0.39 | 0.397 |
| | 66.5-oz can | Ambrosia White Chunk Albacore Tuna in Water | Indonesia | 0.47 | 0.54 | 0.30 | 0.37 | 0.51 | 0.41 | 0.433 |
| | 66.5-oz can | Ambrosia White Chunk Albacore Tuna in Water | Indonesia | 0.31 | 0.29 | 0.28 | 0.32 | 0.36 | 0.46 | 0.337 |
| | 66.5-oz can | Ambrosia White Chunk Albacore Tuna in Water | Indonesia | 0.62 | 0.60 | 0.20 | 0.27 | 0.40 | 0.38 | 0.412 |
| | 66.5-oz can | Ambrosia White Chunk Albacore Tuna in Water | Indonesia | 0.37 | 0.38 | 0.20 | 0.19 | 0.40 | 0.48 | 0.337 |
| WI | 43 oz foil pouch | Chicken of the Sea Premium Wild-Caught Light Tuna in Water | Thailand | 0.23 | 0.22 | 0.20 | 0.20 | 0.26 | 0.23 | 0.223 |
| | 43 oz foil pouch | Chicken of the Sea Premium Wild-Caught Light Tuna in Water | Thailand | 0.06 | 0.08 | 0.08 | 0.07 | 0.07 | 0.08 | 0.073 |
| | 43 oz foil pouch | Chicken of the Sea Premium Wild-Caught Light Tuna in Water | Thailand | 0.25 | 0.25 | 0.24 | 0.26 | 0.28 | 0.31 | 0.265 |
| | 43 oz foil pouch | Chicken of the Sea Premium Wild-Caught Light Tuna in Water | Thailand | 0.25 | 0.26 | 0.22 | 0.23 | 0.09 | 0.10 | 0.192 |
| | 43 oz foil pouch | Chicken of the Sea Premium Wild-Caught Light Tuna in Water | Thailand | 0.23 | 0.23 | 0.04 | 0.05 | 0.23 | 0.23 | 0.168 |